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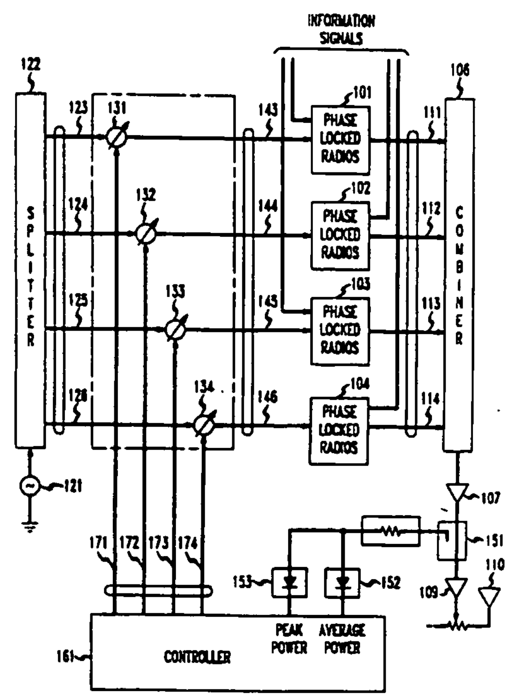
## (54) Method and apparatus for reducing the peak-to-average power in multi-carrier RF communication systems.

(57) Apparatus for controlling a system including a linear amplifier (109) processing a plurality of carrier signals (111-114) of a multi channel carrier system alters the phases (by 131-134) of one or more sources of the multi-channel signals in response to a detected peak envelope power (in 153) or of a peak to average power (in 152) ratio at regular scheduled intervals. This reduces the peak envelope power to average envelope power ratio and enables the reduction in the power rating required by the amplifiers handling the multi-channel signal.

FIG. 1

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## Field of the Invention

This invention relates to multi-channel signal amplification systems in a communication system and to a method and apparatus for increasing the average power handling capacity of such a multi-channel signal amplifier relative to its peak power rating. It is also concerned with preventing variations of the phases of individual carrier signals comprising the multiple channel signal from causing occurrences of very high envelope signal peaks in the multichannel signal.

## Background of the Invention

In wireless telephone communication systems the power signals of many channels are combined into a composite signal. This composite signal is split into many parallel paths and coupled to individual radio transmitters in each parallel path. The output radio transmission signals of the plurality of radio transmitters are combined and amplified in a single power amplifier. Individual signal peaks in each of the parallel paths may coincide and cause a composite peak power to occur at the single power amplifier that greatly exceeds its power handling capacity.

The various radio channels are distributed in frequency with respect to each other in that each operates within a different frequency band. Each channel is FM modulated and hence has a signal of substantially constant amplitude. The peak occurrences of the combined signal is a highly complicated function of the individual carrier frequencies, modulation methods, signal contents and noise. Since the simultaneous occurrence of individual signal peaks can not easily be avoided, a multi-channel signal is subject to power maximums where the peak power significantly exceeds the average power of the envelope due to constructive addition of the individual signals.

U.S. patent 4,064,464 discloses an amplifier system, including a power splitter for dividing an input signal into a plurality of channels and feeding each channel into a plurality of power amplifiers connected in parallel. The several output of the parallel connected power amplifiers are combined into a single output by a subsequent power combiner connected to the paralleled outputs of the power amplifiers. The input to one of the paralleled amplifiers includes a voltage controlled phase shifter that is responsive to a deviation of the power output of the power combiner from a reference value. This feedback arrangement maintains the power output at a regulated value. This is however, an amplification technique having individual amplifiers in each of a plurality of channels rather than amplifying a combined signal of a plurality of channels of radio transmission signals in a single amplifier.

## Summary of the Invention

In accord with the invention peak power in an amplifier, amplifying the power output of a plurality of parallel connected radio transmitters is limited according to the apparatus claim 1 and the method claim 2.

## Brief Description of the Drawing

In the Drawing:

FIG. 1 is a block schematic of an amplifier system control arrangement to limit the peak to average power ratio;

FIG. 2 is a block schematic of an another amplifier system control arrangement to limit the peak to average power ratio;

FIG. 3 is a block schematic of a stored program controller used in the amplifier control systems of FIGS. 1 and 2;

FIGS. 4 and 5 are graphs of waveforms of envelope power processed by the amplifier system; and

FIG. 6 is a flow process diagram of the method of reducing the peak to average power ratio.

## Detailed Description

An exemplary system for reducing the peak to average power in an amplifier processing a plurality of different signal channels spaced apart in frequency from one another; each channel having a different carrier frequency is shown in the FIG. 1. The apparatus shown is included in a cellular base station in which the phase locked radios each handle a different channel in the channel set assigned to the cell served by the cellular base station.

A plurality of phase locked radio transceivers, 101, 102, 103 and 104, are connected to receive audio and data designated as information signals. These signals are FM modulated and transmitted at different carrier frequencies for each of the phase locked transceivers. The FM signals (radio frequency output signals) are individually transmitted, via leads 111, 112, 113 and 114, to a combiner circuit 106 that combines all the modulated carrier signals into a composite modulated signal including all the information supplied to the radios 101-104. This composite signal is applied to the preamplifier 107 and subsequently to a linear amplifier 109 which amplifies the composite signal to a radio transmission level. The linear amplifier output is connected to an antenna 110 for transmission to the cell area.

The frequencies of the carrier signals in each of the radios are synchronized to a reference frequency supplied from a reference signal derived from a reference frequency generator 121. The output of the reference frequency generator 121 is applied to a signal

splitter apparatus 122 which applies the reference frequency signal onto the four leads 123, 124, 125 and 126. These four leads are coupled to the voltage controlled phase shifters 131, 132, 133 and 134, whose operation is discussed subsequently. The output of the phase shifters is connected via leads 143, 144, 145 and 146 to reference signal inputs of the phase locked radios 101-104.

In this illustrative arrangement the carriers of the transceivers are equally spaced apart in frequency. In this instance, the peak to average reduction is most advantageous. Each radio is locked to the same reference frequency supplied to the leads 123-146. Due to thermal effects in the phase locked loops, the carrier frequencies drift with respect to each other and, as shown in FIG. 4, the peaks of several carriers may coincide in time producing a high peak envelope power in the linear amplifier. In general, the envelope of the combined signals are periodic at the rate of $\frac{1}{f}$ is the frequency spacing between carriers. These envelope peaks may exist for extended periods of time, which is associated with the thermal draft of the phase locked transceivers.

The power input to the linear amplifier 109 is sensed by the coupling device 151 which is connected to an average power detector 152 and a peak power detector 153. The values for average power and peak power are applied to a controller 161. The Controller, which may be implemented in either digital or analog form, continuously monitors the peak power to average power ratio of the signal processed by the linear amplifier 109. Controller 161 includes circuitry to evaluate this ratio and uses the information to apply control voltages, via leads 171, 172, 173 and 174, to the voltage controlled phase shifters 131-134. In the illustrative embodiment this control circuit may comprise stored program control, logic arrays or analog circuitry.

In the arrangement of FIG. 1, a 1 to 3 degree phase shift of the reference frequency inputs corresponds to a 60 to 180 degree phase shift at the RF outputs since the ratio of the radio frequency to the reference frequency is equal to 60. The phase shift for each individual carrier is applied to the corresponding reference signal input to which the radio carrier is synchronized. In the illustrative embodiment this reference frequency is in the 15 MHz range.

A typical stored program controller suitable for use as the controller is shown in the FIG. 3. The controller monitors the average and peak envelope powers of the input signal to the Linear amplifier. The average power herein is understood to be the thermal equivalent power, averaged over a time period longer than the fluctuations of the envelope power, perhaps 100 mS. The peak power is that power detected by a classical video diode peak detector, which stores the peak value in a capacitor which decays at a rate somewhat slower than the frequency of occurrence of the peaks.

By measuring both the peak and average powers, the controller of FIG. 3 can compute the peak to average ratio of the signal and optimize for a minimum ratio. The hardware implementation, as shown in the FIG. 3, includes two analog to digital converters, 301 and 302 which receive input from a peak detector (153 in FIG.1) and an average power detector (152 in FIG. 1) respectively, and apply a digitized version of the peak and average power to a microprocessor. The microprocessor includes associated RAM (304) and ROM (305) memory capacity, which provide memory storage and stored instructions for controlling the processing of the sensed power signals and generating the output control signals to control the phase shifting circuitry (131 - 134 in FIG.1). The microprocessor 303 feeds digital phase shift control signals to one or more of a set of digital to analog converters 331 - 334 which in turn supply analog control signals to control the phase shift circuits 131-134 shown in FIG. 1. While the illustrated controller uses a microprocessor and digital signals it is to be under stood that a completely analog controller can be used, with sample and holds and comparators and op amps.

Optimization of the peak to average power ratio is done with a successive trial and error procedure, since the correlation between phase of a given radio and the peak to average ratio of the combined radio signal is very complex, and because the absolute phase of a given radio is not easily controllable. The controller adjusts one or more of the phase shifters at a time, then monitors the peak to average ratio. If there is an improvement (decrease) in the peak level. the controller continues phase adjustment in the same direction. When a minimum peak to average ratio is achieved, as evidenced by a dip in the peak power envelope, the controller stops adjustment of that phase shifter and goes on to the next phase shifter in sequence. Each phase shifter is set in sequence, and then the controller repeats the cycle. In some applications it may be sufficient to just monitor the peak value of the power envelope.

The process of changing the phase of a radio, according to the instructions of the stored program of the controller, for a particular one of the radios N, is shown in flow chart form in the FIG. 6. The flow starts in the terminal 601 and the instructions of block 603 cause the peak envelope and average power to be measured and the peak envelope to average power ratio to be calculated. The instructions of decision block 605 determine if the absolute difference between the most recent peak/average ratio measurement and the previous peak/average ratio measurement is greater than some minimum quantum phase value. This quantum value is an absolute value of phase change below which the phase of the current radio is considered to be optimum.

If the absolute difference in decision block is greater than the minimum quantum phase value the flow proceeds to decision block 609 whose instructions determine the most recent peak/average ratio is greater than the previous peak/average value. If it is not the phase of radio N is changed by some quantum value. The last computed peak/average ratio is made the most recent value in the block 615 and the flow process returns to the block 603.

If the response to the evaluation of decision block 605 is a no answer the flow proceeds to the block 607 which changes the N designation of the radio being adjusted to the next radio. The phase of this radio is changed as per the instructions of block 613.

In response to an affirmative response to decision block 609 the flow proceeds to block 611, whose instructions change the direction of the phase shift implemented. The radio phase is shifted in accord with the instructions of block 615.

The wave form, of FIG. 4 shows the occurrences of high peaks in the multicarrier signal envelope of the type that limit the peak power handling capacity of a linear amplifier system. The peaks 401 are significantly higher than the average power level 402.

The improvement achieved by the method and apparatus to reduce these peaks is shown in FIG. 5 where the peaks 501 relative to the average power level 502 is much reduced compared to the FIG. 4.

An alternative arrangement for preventing high to peak-to-average power ratios from occurring is shown in the FIG. 2. The system components are substantially identical to those described with reference to the FIG. 1 system, but their relative positioning is altered. The chief alteration is the positioning of the voltage controlled phase shifters 231-234 to phase shift the carrier at the outputs of the transceivers 201-204. This repositioning requires phase shifts in the order of 60 to 180 degrees to be effective. Otherwise the operation is substantially similar to the operation of the phase shift system of FIG. 1. The controller used here is identical to the controller of FIG. 3 except for the phase shift increment used.

## Claims

1. In a power amplifier system for a radio transmission communication system;

   a power splitter (122) for dividing an input composite signal into a plurality of parallel channels (123-126);

   a power combiner (106) connected to combine the signals on the parallel channels into a single output channel (107);

   CHARACTERIZED BY:

   each of the parallel channels including a radio transmitter (101-104); an amplifier for amplifying the signal on the single output channel (109);

   means for monitoring a peak power level (153) of the signal on the single output channel;

   means for monitoring an average power level (152) of the signal on the single output channel; means for developing a ratio of peak power to average power (161) connected to receive inputs form the means for monitoring a peak power and means for monitoring an average power;

   means for altering phases (131-134) of the signals of the radio transmitters in response to the means for developing when the ratio exceeds a specified value.

2. In a power amplifier system processing a composite radio carrier signal in a plurality of parallel channels each including a radio transmitter with the parallel channels fed into a single channel including a single power amplifier, a method of increasing an average power handling capacity of the single power amplifier, CHARACTERIZED BY the steps of:

   monitoring a peak power level of the single channel handled by the single power amplifier and determining if it exceeds a power threshold;

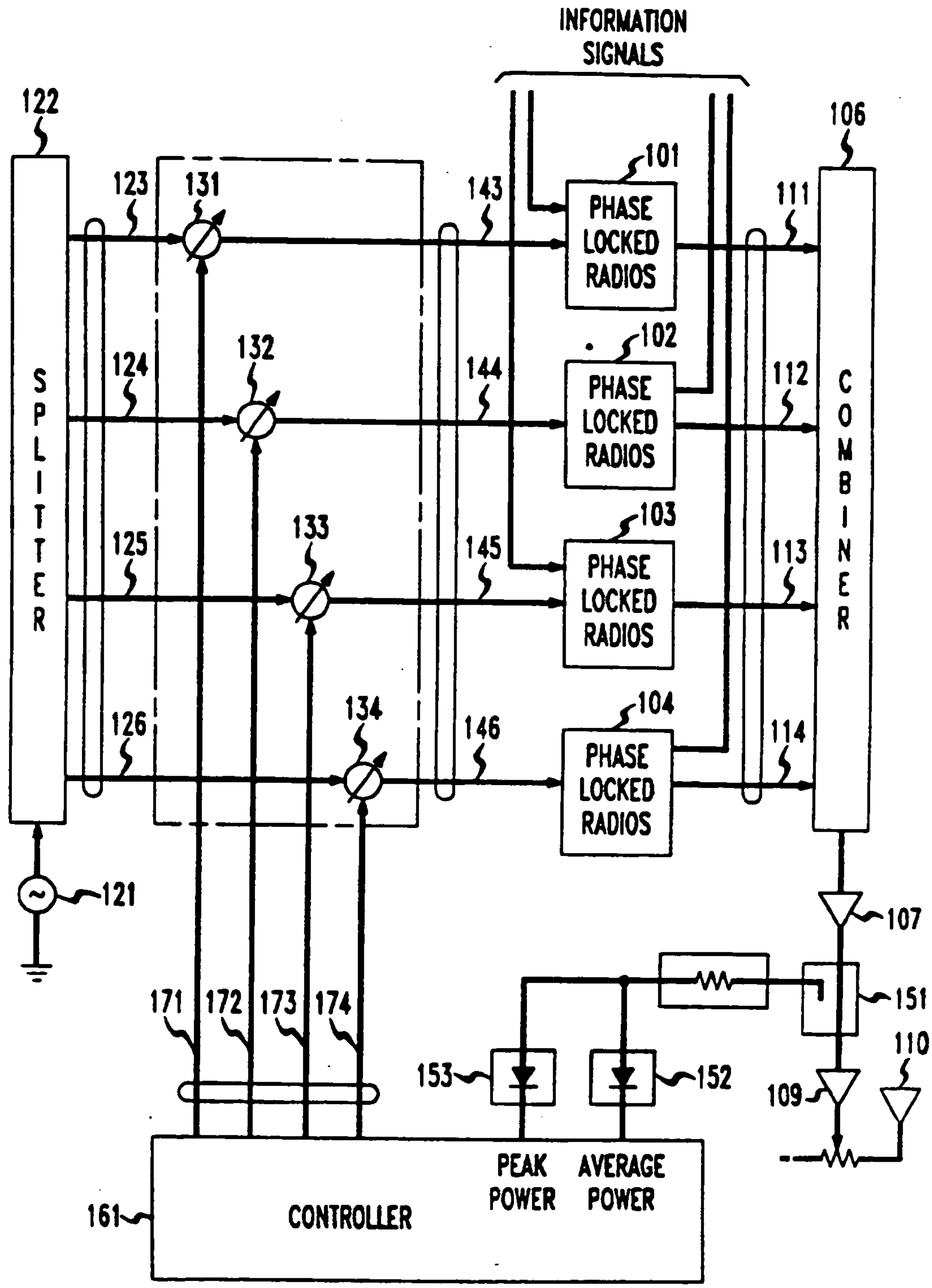
   altering a phase of one of the radio carrier signal in at least one of the parallel channels if the peak power exceeds the threshold;

   again determining if the peak power exceeds the threshold;

   altering a phase of the radio carrier signal in another one of the parallel channels; and

   ceasing alteration of phases of the radio carrier signals when the peak power does not attain the threshold.

*FIG. 1*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SPLITTER
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144
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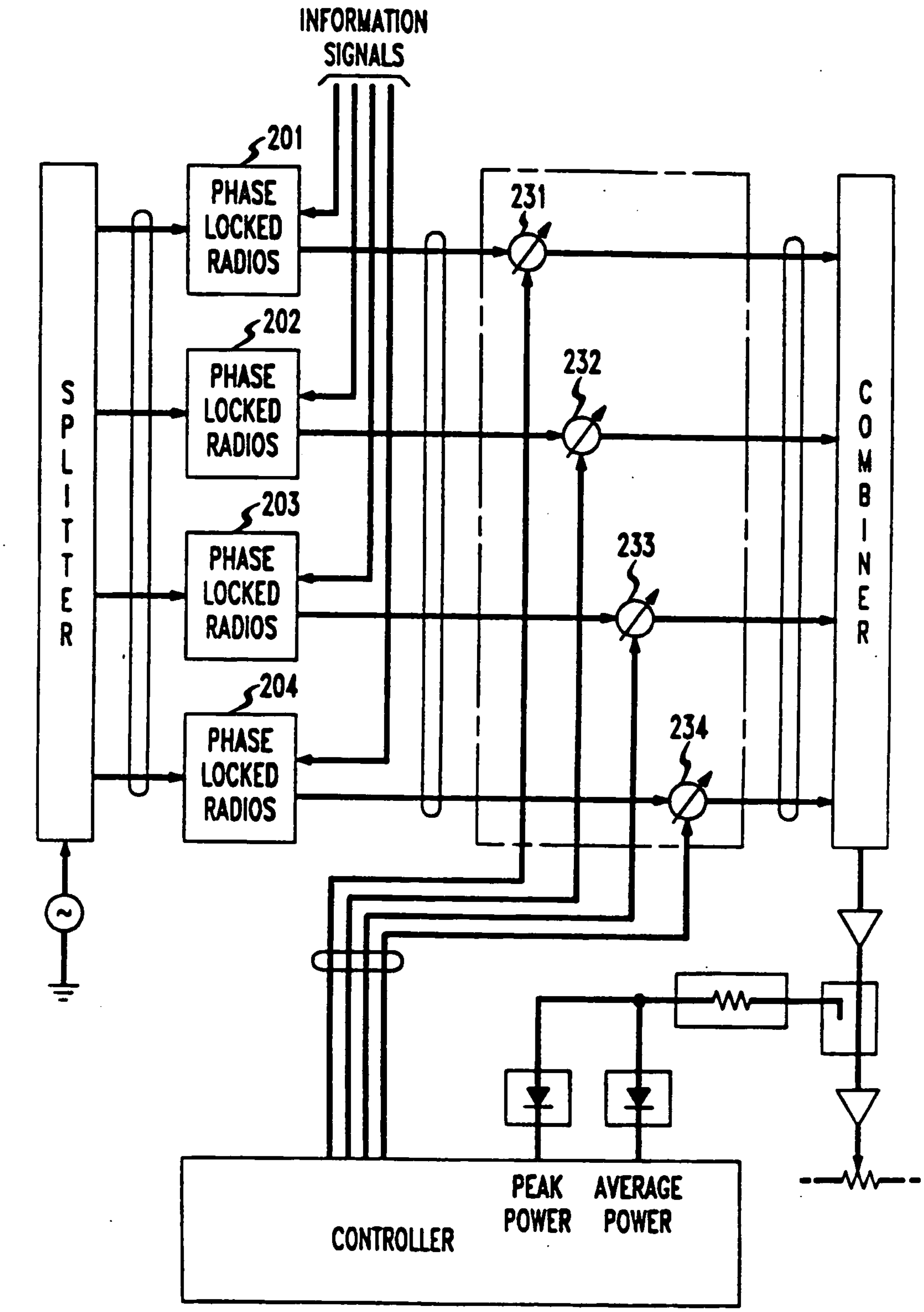
102
PHASE LOCKED RADIOS
103
PHASE LOCKED RADIOS
104
PHASE LOCKED RADIOS
111
112
113
114
106
COMBINER
107
151
110
109
152
153
121
171
172
173
174
161
CONTROLLER
PEAK POWER
AVERAGE POWER

FIG. 2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202
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204
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SPLITTER
231
232
233
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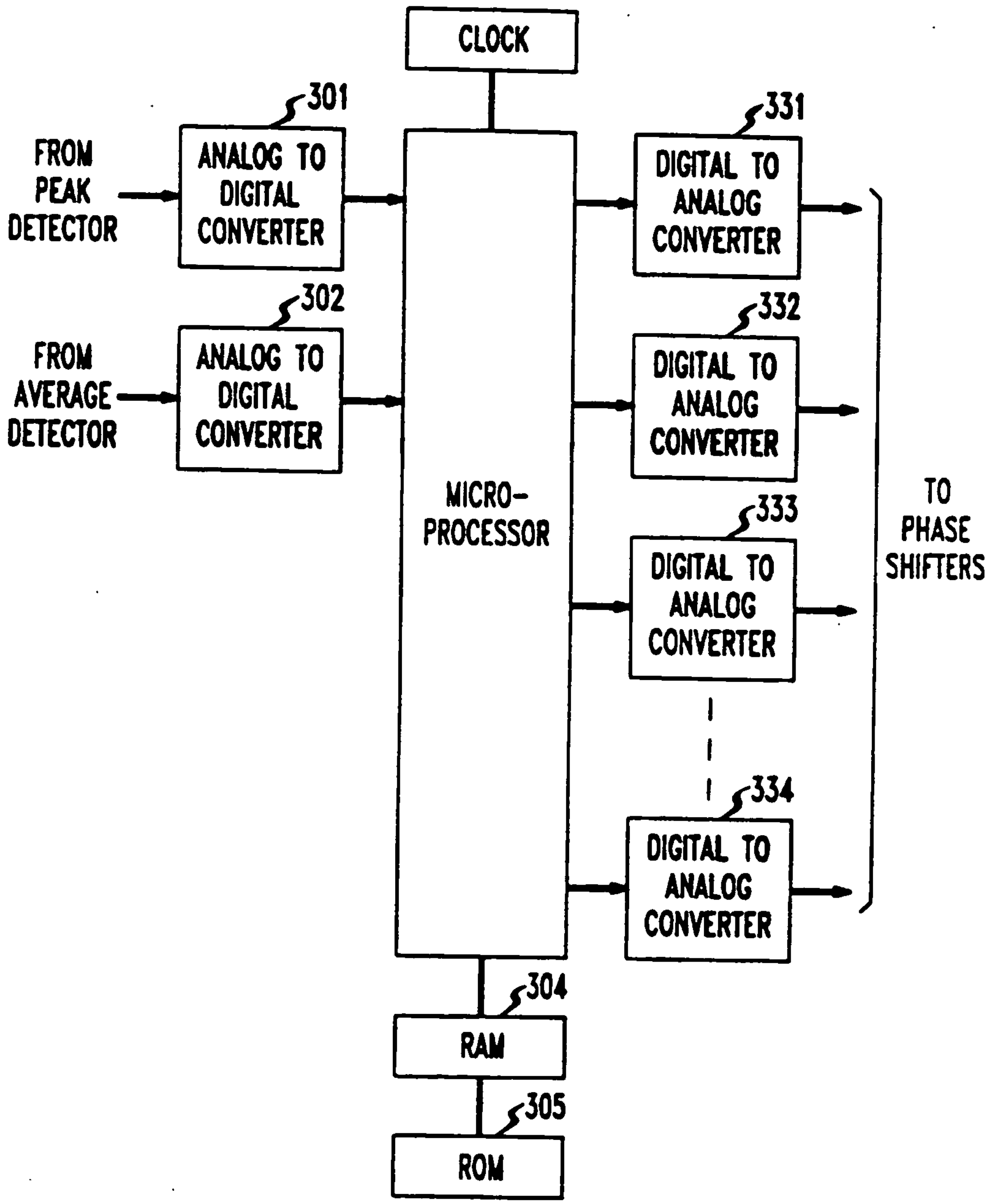
COMBINER
CONTROLLER
PEAK POWER
AVERAGE POWER

FIG. 3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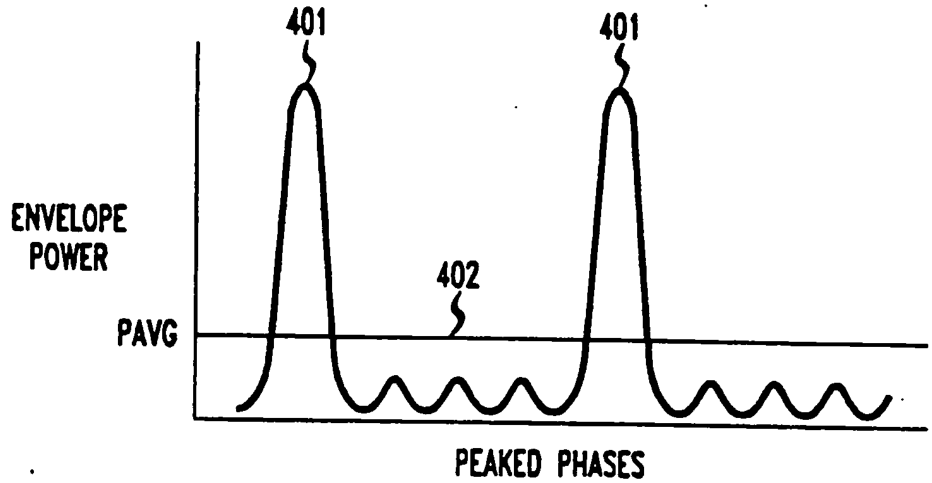
301
FROM PEAK DETECTOR
ANALOG TO DIGITAL CONVERTER
302
FROM AVERAGE DETECTOR
ANALOG TO DIGITAL CONVERTER
MICRO-PROCESSOR
331
DIGITAL TO ANALOG CONVERTER
332
DIGITAL TO ANALOG CONVERTER
333
DIGITAL TO ANALOG CONVERTER
334
DIGITAL TO ANALOG CONVERTER
TO PHASE SHIFTERS
304
RAM
305
ROM

FIG. 4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401
ENVELOPE
POWER
402
PAVG
PEAKED PHASES

FIG. 5

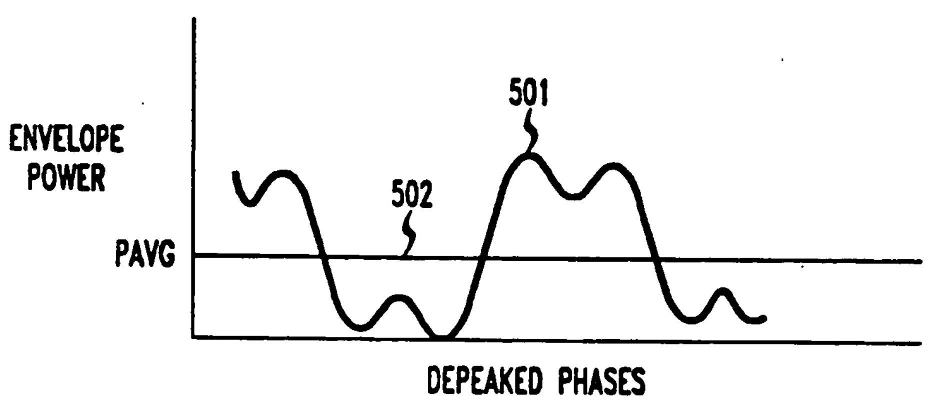
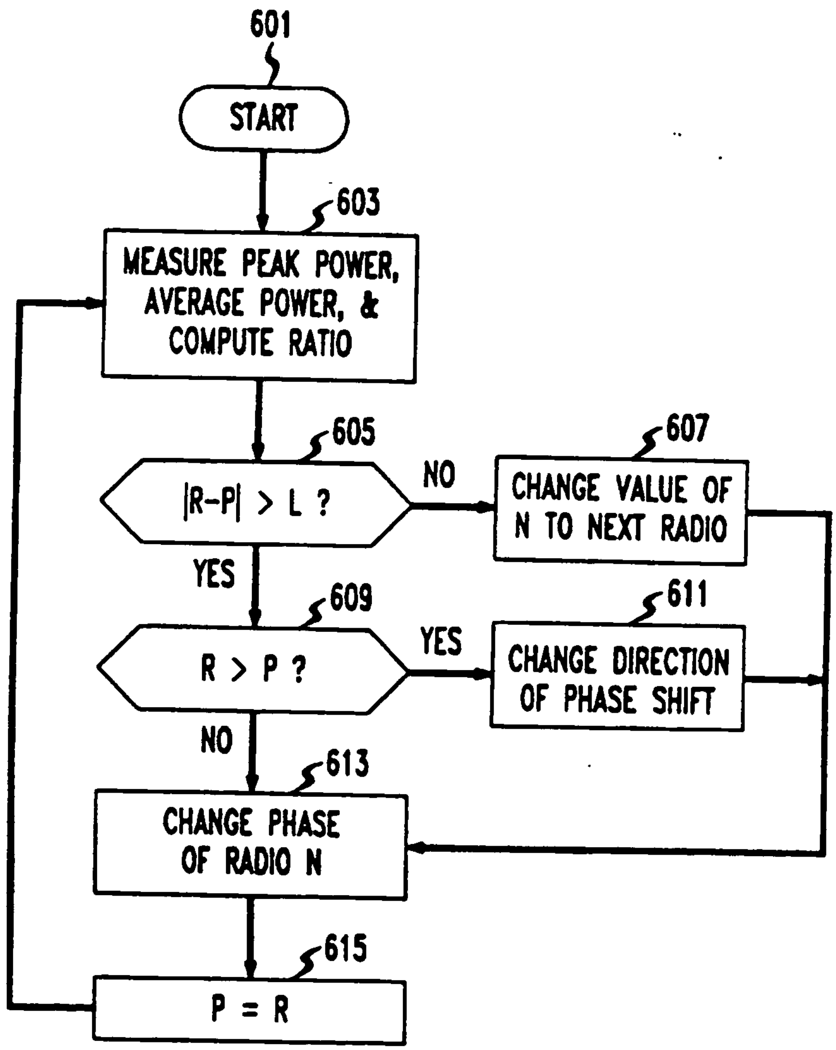

501
ENVELOPE
POWER
502
PAVG
DEPEAKED PHASES

*FIG. 6*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START
603
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605
|R-P| > L ?
NO
607
CHANGE VALUE OF N TO NEXT RADIO
YES
609
R > P ?
YES
611
CHANGE DIRECTION OF PHASE SHIFT
NO
613
CHANGE PHASE OF RADIO N
615
P = R